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Global Space-based Inter-Calibration System

Newsletter – Winter 2015 Issue

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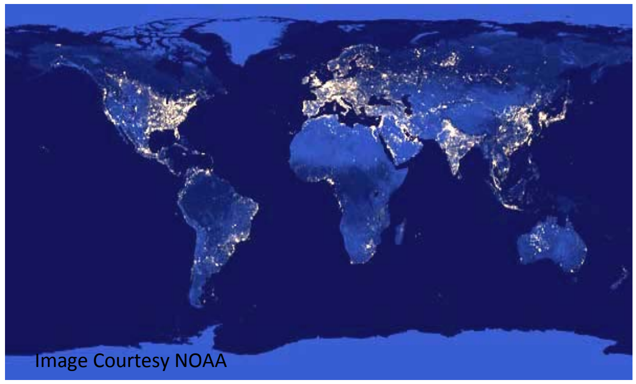

DSCOVR launched by Space-X on 11 Feb 2015, from Cape Canaveral.

Image above shows Earth Night Lights as viewed by D/N band of VIIRS

The Conundrum of SI traceability at L_{min} for the VIIRS Day/Night Band

by Changyong Cao, NOAA

It is commonly accepted that any good measurements, including those from satellites, should ideally be made SI traceable, which is defined as the "property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty" (VIM). For the VIIRS onboard calibration, the pre-launch " reference" would be the irradiance sources used and maintained at the metrology institute. After the satellite is launched into orbit, the reference becomes the solar irradiance which has been extensively studied with well known uncertainties. After taking into account all the uncertainties in the error budget analysis, it is concluded that the VIIRS onboard solar diffuser calibration can achieve a calibration with ±2% (1-sigma) uncertainty.

In the case of the VIIRS Day/Night Band (DNB), the nominal value for this solar diffuser in-band radiance is on the order of 1 000 000 nW/cm^2-sr (nW= nano watts, or 0.001 W/cm^2-sr) which is in the low gain stage (LGS). However, at night, the radiances are much lower. For example, the brightest spot in Geneva has a typical radiance on the order of 200-500nW/cm^2-sr (Figure. 1).

While this ±2% uncertainty is good enough for low-gain applications where the radiances are high during the daytime, the uncertainty increases greatly when the calibration is transferred to the medium and high gain stages (MGS and HGS). For example, the uncertainty for the DNB HGS has a specification of 30% at L_{min} (3 nW/cm^2-sr) and can be up to 100% in some cases. As a point of comparison, a crab fishing boat rescued in Alaska in 2013 showed a DNB radiance value on the order of 3.6 nW/cm^2-sr, which is at the level of

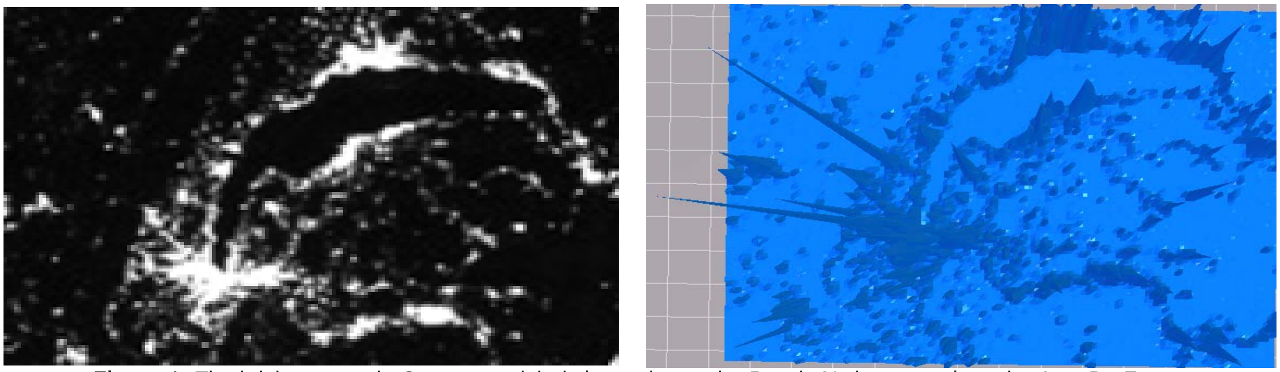

Figure 1. The brightest spot in Geneva at night is located near the Paquis Nation area along the Ave. De France, with radiance typically 200-500nW/cm2-sr (after Cao and Bai, 2014)

L_{min}. If VIIRS DNB had been 30% too low, the boat may have not been detected. This brings up the issue that a 2% uncertainty at the solar diffuser is actually not good enough for low light applications. One can argue that even at 30-100%, it is still SI-traceable because of the chain of calibration has not been technically broken, but unfortunately, at this point the SI traceability does little help to the situation. Given the above scenario, it is clear that the solar diffuser calibration on VIIRS, while adequate for most other applications, is not sufficient for reducing the uncertainties of the HGS of the VIIRS DNB. Part of the challenge is that since the VIIRS DNB is extremely sensitive to any light, it is difficult to determine the offset in the calibration. For example, most satellite instruments rely on space view to derive the calibration offset. However, for DNB, the space view is not dark enough and stars can be seen. In operations, we use the darkest part of the ocean during the new moon. But then again, the air glow contributes light to the observed radiances which has to be accounted for. In addition, small nonlinearities and transfer between gain stages all add to the uncertainties. The future CLARREO mission, which will bring down the uncertainty to 0.1% level, will help significantly compared to the current 2%. However, it may still be challenging for the low radiance applications at night.

To reduce the uncertainties of the DNB calibration, scientists at NOAA and NIST are working together to experiment with ground-based light sources which can be measured accurately and observed by the DNB. This would provide traceability to the stated references independently from the solar diffuser which is most suitable for the low gains. A Small Business Innovative Research (SBIR) project is being developed at NOAA to facilitate the development of this capability and a feasibility study will be initiated in 2015.

The moral of the VIIRS DNB story is that SI traceability, while already difficult to achieve, has to be suitable for the intended purpose. A simple statement of SI traceability may not be sufficient for a complex instrument such as VIIRS, where there are numerous applications and each has its own requirements. There is sometimes also a lack of consistent definition of the calibration uncertainties across missions. For example, some missions define the uncertainty at 100% reflectance, while others define them at the L_{typ} which is typical radiance. The difference between these two definitions can be very large and may have significant implications on instrument performance, and cost as well.

Similar issues exist for other bands such as in the 2 µm spectral region, where the ocean color has a typical radiance on the order of 0.12W/m^2-sr-µm. As a result, the VIIRS calibration of 2% uncertainty, while sufficient for some users, may be wholly unsuitable for more demanding applications at low radiance levels. As for the DNB, quantitative analysis of the nightlight radiances is still in the infancy stage (Cao and Bai, 2014). But as the users become more sophisticated, a 30% uncertainty would almost certainly not be sufficient, for example, for applications such as change detection in nightlights. Therefore, there is a long way to go in reducing the uncertainties, especially at low radiances.

Reference:

Cao C. and Y. Bai Y, 2014: Quantitative analysis of VIIRS DNB nightlight point source for light power estimation and stability monitoring. *Remote Sens.*, **6(12)**, 11915-11935 (http://www.mdpi.com/2072-4292/6/12/11915).

Discuss the Article

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S-NPP VIIRS Thermal Emissive Bands On-orbit Performance

by Boryana Efremova and Jack Xiong, NASA

The first Visible Infrared Imaging Radiometer Suite (VIIRS) instrument has successfully operated for more than three years since its launch on-board the Suomi National Polar-orbiting Partnership (S-NPP) spacecraft. The 22 VIIRS spectral bands provide observations with moderate (M-bands) and high (I-bands) spatial resolution of 750 m and 375 m at nadir, respectively. The thermal emissive bands (TEB) covering wavelengths from 3.7 to 12.0 µm are listed in Table 1. M13 collects data with both high gain (HG) and low gain (LG). Key environmental data records relying on TEB measurements include sea/land surface temperature, active fire products, etc. VIIRS uses

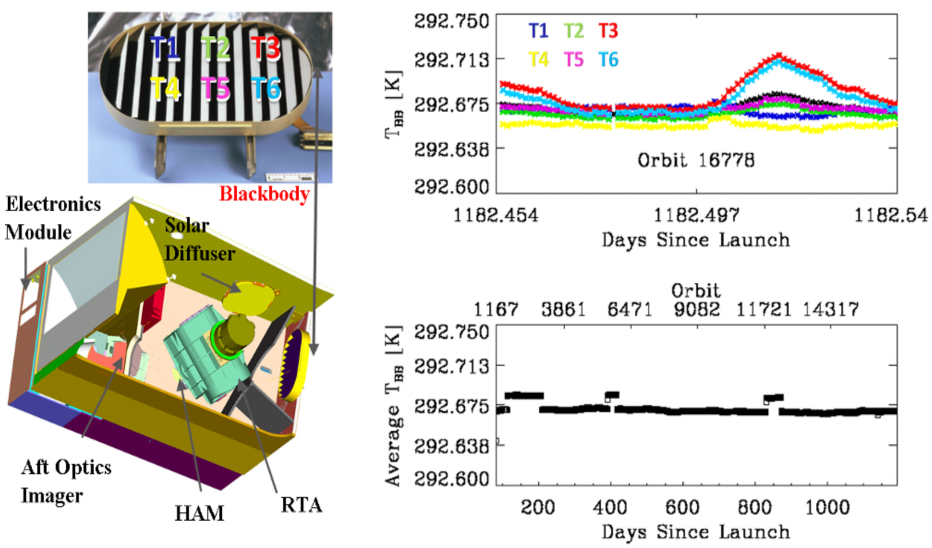

Figure 1. Left: Schematic of VIIRS instrument and BB. Right: Orbital BB temperature measurements (top); Long term BB temperature trend (bottom).

a rotating telescope assembly (RTA) followed by a half-angle mirror (HAM) (Figure 1), providing a wide swath of nearly 3000 km. An overview of the VIIRS on-orbit calibration methodology and initial on-orbit performance can be found in Xiong et al. (2014). Like its heritage sensor MODIS, the TEB are calibrated by an on-board blackbody (BB). The following equation

$$L_{ap} = \frac{F\sum_{i=0}^{2} c_i\, dn^i - (RVS_\theta - RVS_{SV})L_{BG}}{RVS_\theta} \qquad (1)$$

is used to retrieve the at-aperture spectral radiance L_{ap} from the background subtracted detector output dn, by applying calibration coefficients c_i measured pre-launch. On-orbit changes in the detector response are corrected for by the F-factor. The difference in instrument self-emission between the earth view (EV) and the space view (SV) L_{BG} includes mainly emission from the HAM. The response versus scan-angle (RVS) function accounts for variation of the HAM reflectivity with scan angle.

On-orbit Performance

The major performance characteristics (BB temperature, TEB F-factors, NEdT, instrument temperatures and nonlinearity) are regularly trended. The long-term trending is based on data taken each orbit near the spacecraft passage over the South Pole; thus, it excludes any orbital variations. The temperature of the BB (T_{BB}) is nominally controlled at 292.5 K; it is measured every scan by six thermistors (top panel of Figure 1). The trending of T_{BB} --the average of the six thermistors-- shows a very stable BB performance (bottom right panel of Figure 1). The small (~15 mK) discontinuities are due to two slightly different settings, and do not affect the data quality. On a short-term scale, there are some orbital variations; the individual readings of the six thermistors over one orbit are illustrated in Figure 1 (top right). The orbital variations in both BB average temperature and temperature uniformity are well within the requirements. Since launch, twelve BB warm-up/cool-down (WU/CD) cycles have been successfully performed, during which the BB temperature was varied from ambient (about 267 K) to 315 K.

The F-factor is calculated each scan by taking the ratio between the estimated radiance reaching the detector viewing the BB and the measured radiance retrieved using the pre-launch calibration coefficients, c_i, times the background subtracted detector output at the BB view, dn_{BB}.

$$F = \frac{RVS_{BB}L_{BBap} + (RVS_{BB} - RVS_{SV})L_{BG}}{\sum_{i=0}^{2} c_i\, dn_{BB}^i}, \quad (2)$$

where RVS_{BB} is the RVS at the BB view angle, and L_{BBap} is the at aperture radiance from the BB with small contribution from instrument self emission reflected off the BB (Efremova .et.al, 2014). The F-factor is applied each scan (Eq. 1) to correct for on-orbit changes in the detector gain. Since launch, the TEB F-factor has been very stable with I5 showing the most noticeable band-averaged trend of about 1%. The rest of the bands are within 0.4%. There is a minor annual feature in the trend of the long-wave infrared (LWIR) F-factors which is correlated with the instrument temperatures peaking at the passage of the Earth through perihelion. Some small discontinuities are coincident with spacecraft maneuvers and/or anomalies. In general, TEB detector performance is very stable and shows little degradation. Small (up to 0.1%) orbital variations are present and correlate with the orbital oscillation of the BB temperature. For details see Efremova et al. (2014).

Table 1. VIIRS TEB central wavelengths and NEdT levels (from BB WU/CD in Dec 2014).

Band	M12	M13	M14	M15	M16	I4	I5
Wavelength [μm]	3.70	4.05	8.55	10.76	12.01	3.74	11.45
T_{TYP} [K]	270	300(HG) 380 (LG)	270	300	300	270	210
NEdT [K] at T_{TYP} Requirement	0.396	0.107	0.091	0.070	0.072	2.5	1.5
NEdT [K] at T_{TYP} Dec 2014	0.12	0.04	0.06	0.03	0.03	0.4	0.4

The Noise Equivalent differential Temperature (NEdT)--representing the sensitivity of the instrument--is trended at nominal BB temperature. It is also calculated at the specified typical temperature for each band during WU/CD cycles. From launch to present, the NEdT performance has been extremely stable. The most recent results at T_{TYP} are listed in Table 1.

On-orbit calibration coefficients c_0, c_1, and c_2 are derived at each WU/CD cycle, trended and compared to pre-launch, and can replace the pre-launch values if necessary. The results are consistent among the twelve WU/CD cycles performed and do not indicate significant changes in the detector performance therefore the calibration coefficients have not been updated.

Summary

The S-NPP VIIRS TEB have been operating for over three years, showing stable performance compliant with requirements. Small (1%) degradation is observed in I5, while the rest of the TEB are within 0.4%.

Acknowledgement: The authors would like to acknowledge contributions from other members of the NASA VIIRS Characterization Support Team (VCST).

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Efremova, B., J. McIntire, D. Moyer, A. Wu, and X. Xiong, 2014: S-NPP VIIRS thermal emissive bands on-orbit calibration and performance. *J. Geophys. Res.-Atmos.*, **119**, 10,859-10,875, doi:10.1002/2014JD022078.

Xiong, X., J. Butler, V. Chiang, B. Efremova, J. Fulbright, N. Lei, J. McIntire, H. Oudrari, J. Sun, Z. Wang, and A. Wu, 2014: VIIRS on-orbit calibration methodologies and performance. *J. Geophys. Res.-Atmos.*, **119**, 5065-5078, doi:10.1002/2013JD020423

Discuss the Article

Update on the Intersatellite Calibration of NOAA HIRS CO_2 Channels for Climate Studies

by Zhuo Wang, Changyong Cao and Bin Zhang, NOAA

In a collaborative effort among NOAA/NESDIS/STAR, the University of Wisconsin and the University of Maryland, scientists are working together to improve the consistency in the calibration of the 30-year time series of HIRS data, They found that the differences and uncertainties in the HIRS spectral response function (SRF) are the most likely the causes of the large inter-satellite radiance biases of HIRS channels 4, 5, and 7 (Wylie et al. 2005; Cao et al. 2009; Chen and Cao 2012; Chen et al. 2013; Menzel et al, 2013). To quantitatively recalibrate the SRFs of the HIRS longwave CO_2 channels, the impacts of SRF differences and uncertainties are separated and analyzed.

The study shows that the radiance bias contributed by SRF differences for HIRS can be estimated from a radiance linear correlation model. After subtracting the intersatellite radiance bias due to SRF difference, there are still obvious intersatellite biases for HIRS channels 4, 5 and 7 which are believed to be caused by SRF uncertainties. Meanwhile, channel 6 is less sensitive to spectral changes than other channels.

The impact of SRF uncertainties on HIRS radiance are analyzed by shifting the prelaunch measured SRF. The following linear model is used to predict the HIRS radiance changes in the seven CO_2 channels and one water vapor channel:

$$\Delta R_i^m = \Delta SRF \left(\sum_j \beta_{ij}^m R_j^m + c_i^m \right) \quad (1)$$

(see Eq. 5 and coefficients provided by Table 3 in Chen et al. (2013) for more details).

The relative SRF shifts for NOAA-6 to -8 are calculated based on SNO analysis. However, using direct SNO method for the SRF corrections before NOAA-9 is difficult due to SNO gaps between NOAA-8 and -9. Since NOAA-7 and -9 have common observation time periods with GOES-6, a double differencing method is applied. The SRF shift between NOAA-7 and GOES-6 is estimated first, and the shift between GOES-6 and NOAA-9 is then calculated. As a result, the SRF shift between NOAA-7 and NOAA-9 is obtained .

Therefore continuous SRF corrections for all the satellite pairs are carried out. Figure 1 shows the radiance ratio between different satellite pairs before and after SRF corrections, in which the new SNO data from 1981 to 2010 including earlier satellites (NOAA-6 to -9) (cs.star.nesdis.noaa.gov/NCC/METOP) are used to update Chen et al.'s (2013) work.

Besides the model approach, NOAA HIRS observations can be simulated by convolving the hyperspectral MetOp-A IASI measurements at SNO locations with HIRS SRFs. The SRFs of the longwave HIRS CO_2 channels 4-7 are recalibrated based on the optimized

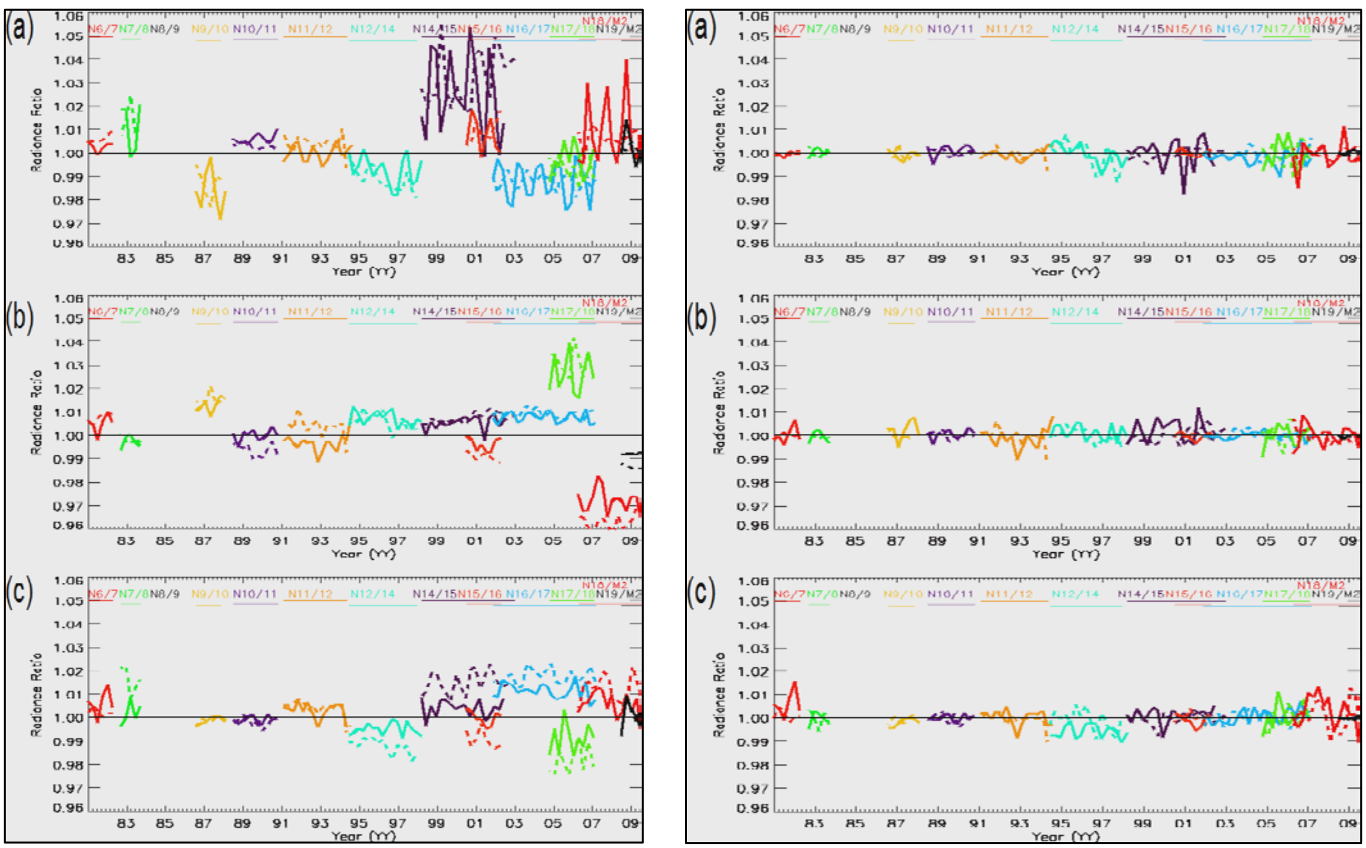

Figure 1. Time series of inter-satellite biases of HIRS longwave CO2 channels for NOAA-6 to -19 and MetOp-A before (left panel) and after (right panel) applying the intermediate SRFs. Solid lines represent SNO comparisons in the south polar region; dashed lines in the north polar region: (a) Ch 4, (b) Ch 5 and (c) Ch 7.

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SRF shifts with central wave number changes from 0 to 3 cm^{-1} for NOAA-9 to -19. Figure 9 in Chen et al. (2013) shows shifting the SRFs effectively minimized the intersatellite mean radiance biases to zero for channels 4, 5 and 7.

The impact of recalibration on climate studies of clouds was also evaluated in *Chen et al. (2013)*, and the results show the SRF corrections are very important for the HIRS cloud top pressure (CTP) estimates to meet the 50 hPa accuracy requirement. The original intersatellite HIRS radiance biases were as large as 3to 4%, which cause uncertainties 3 to 4 times larger than The World Meteorological Organization's Global Climate Observing System (GCOS) 15-hPa requirement for CTP trends. The SRF recalibration reduces the mean intersatellite HIRS biases toward zero with the relative residual uncertainty between consecutive satellites to less than 1%, meeting the GCOS requirements. However the absolute bias could be large using this method.

Recently additional studies have been evaluated by scientists at the Space Science and Engineering Center (SSEC) at the University of Wisconsin–Madison [*Menzel et al. 2015*], summarized as follows:

(1) They used the new SNO dataset of Metop-A IASI–HIRS to estimate SRF shift implied by HIRS-HIRS SNOs, and evaluated the impact of SRF shift on inter-satellite radiance (or BT) biases for various atmospheric conditions through the above linear model. Optimized SRF shifts minimizes the RMS of biases to less than 1%. Dividing the day into four time periods mitigates (but does not eliminate) the effects of orbital drift.

(2) The new HIRS radiance data are used to reprocess the HIRS derived CTP and produce atmospheric clear sky water vapor products (including total precipitable water (TPW) and upper tropospheric humidity).

(3) The HIRS TPW trend is compared with that from Aqua MODIS, and a recalibrated IR split window is needed to mitigate the sensor-to-sensor TPW differences. There was decrease in TPW from 2002 to 2008 and increase after 2008.

Overall, after recalibrating the HIRS sensors, the newly processed HIRS radiance record from 1978 onwards showed more consistent climate trends.

References:

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Chen, R. and C. Cao, 2012: Physical analysis and recalibration of MetOp HIRS using IASI for cloud studies, *J. Geophys. Res.*, **117**, D03103, doi:10.1029/2011JD016427.

Chen, R., C. Cao, and W. P. Menzel, 2013: Intersatellite calibration of NOAA HIRS CO_2 channels for climate studies, *J. Geophys. Res. Atmos.*, **118**, 5190–5203, doi:10.1002/jgrd.50447.

Menzel, W.P., and Coauthors, 2015: Recalibrating HIRS sensors to produce a 30 year record of radiance measurements useful for cloud and moisture trend analysis, *20th Conf. Sat. Met. Ocean.*, AMS Phoenix, AZ, 1B.2.

Wylie, D., D. L., Jackson, W. P. Menzel, and J. J. Bates, 2005: Trends in global cloud cover in two decades of HIRS observations. *J. Cli.*, **18**, 3021–3031.

Discuss the Article

CLARREO: Climate Change Observations and Calibration Standard

by C. Lukashin, B.A. Wielicki, R.R. Baize, and the CLARREO Science Team NASA

The Climate Absolute Radiance and Refractivity Observatory (CLARREO) is a high priority NASA Decadal Survey mission in formulation. CLARREO observations establish new climate change benchmarks with high absolute radiometric accuracy and high statistical confidence across a wide range of essential climate variables (Wielicki et al. 2013). CLARREO provides the data necessary to accelerate decisions on public policy concerning climate change by 15 to 20 years. Earlier and better informed decisions provide a large economic benefit to the world, estimated to be ~$12 trillion over the next 40 to 60 years (Cooke et al. 2013). The CLARREO benchmarks are derived from measurements of the Earth reflectance (from 0.32 to 2.3 μm with

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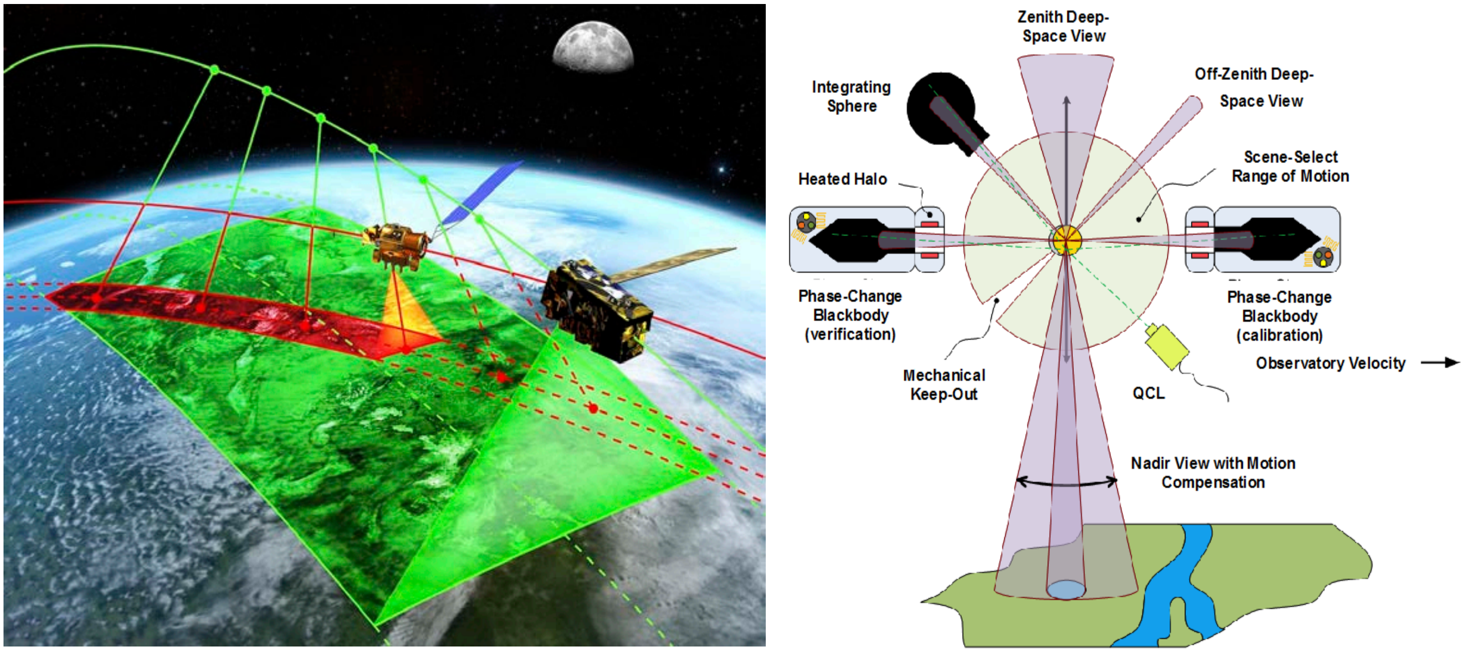

Figure 1(A/B): Concept of CLARREO RS inter-calibration operations – on-orbit temporal and angular data matching (left, Figure 1A), and CLARREO IR measurements and instrument calibration (right, Figure 1B).

accuracy 0.3% $k = 2$) and thermal infrared emission (from 5 to 50 µm with accuracy 0.1K $k = 3$) spectra. Atmospheric refraction and accurate temperature profiles are derived from radio occultation measurements. CLARREO's inherently high absolute accuracy will be verified and traceable on-orbit to *Système International units.*The mission provides the first orbiting reference calibration standard for other radiometric sensors by design. CLARREO's ability to establish a calibration standard for the infrared (IR) and reflected solar (RS) radiometers – including CrIS, IASI, CERES, VIIRS, Landsat, and all geostationary satellite radiometers – will improve the analysis of a wide range of Earth observations. The concept of CLARREO RS inter-calibration operations for on-orbit temporal and angular data matching is shown in Figure. 1A. These operations are enabled by the RS instrument pointing and provide sufficient sampling for all viewing geometries. The reference inter-calibration in the IR is accomplished by collecting a sufficient number of collocations from Simultaneous Nadir Overpasses (SNO's) with other sensors. The mission's inter-calibration operations will also include accurate spectral surface reflectance for selected surface sites. CLARREO inter-calibration algorithms are tested by comprehensive simulations and sampling estimates, and being implemented into the Multi-Instrument Inter-Calibration framework (Wielicki et al. 2014).

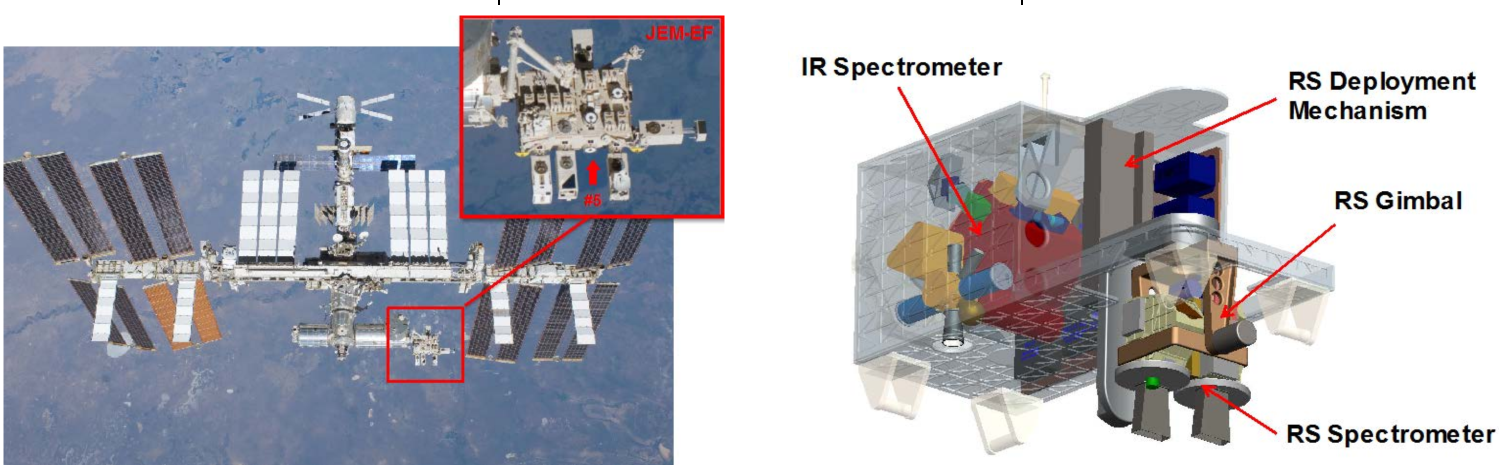

Figure 2: Concept of CLARREO mission option on the ISS: Location example on Japanese Experiment Module (left), and Configuration of CLARREO payload (right).

Sampling studies demonstrated that the CLARREO Baseline Mission can achieve its science objectives (100%) by flying 6 instruments in two 90 degrees inclination polar orbits at 607 km altitude. This orbit choice is well-suited to CLARREO's requirements and assures full diurnal cycle sampling for spectral climate benchmarking as well as full reference inter-calibration sampling over all climate regimes and all satellite orbit thermal conditions. The CLARREO Minimum Mission with 3 instruments in a single 90 degrees inclination polar orbit can achieve 62% of the Baseline Mission science at reduced cost. An alternative mission concept is to fly two CLARREO instruments, RS and IR spectrometers, on the International Space Station (ISS) as illustrated in Figures 2a and 2b. Because of the higher reliability of the ISS as a spacecraft, thereby allowing a longer climate record, this option offers the best overall science value of 73% for the lowest cost. Due to the ISS's 52-degree inclination orbit, CLARREO will not have coverage of Earth's polar regions; however, flying in a precessing orbit will significantly enhance sampling for inter-calibration of existing sensors.

CLARREO successfully passed its Mission Concept Review in November 2010. However, due to a NASA budget decrease in February 2011, CLARREO remains in formulation phase. The CLARREO IR and RS Spectrometers and RO instruments are mature, achieving Technology Readiness Levels of 6 and higher (Wielicki et al. 2014). One of the most critical aspects of CLARREO instrument design is the advance in absolute calibration of parameters susceptible to drift and error on-orbit. The infrared calibration (Figure 1b) relies on phase change cells at −39, 0, and 30°C to verify thermistor accuracy, a quantum cascade laser and heated halos to verify blackbody emissivity, optics design to verify polarization sensitivity, and a quantum cascade laser with integrating sphere to verify instrument spectral response. The verification of Earth's spectral reflectance accuracy on-orbit relies on rotating the entire instrument to view the Moon at a constant phase angle as a stable single-level reflectance source, and the Sun in combination with filters and precision apertures for nonlinearity determination. The team continues to advance the Calibration Demonstration Systems for CLARREO IR and RS instruments, and to develop new cost-efficient mission scenarios

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Wielicki et al., 2014: CLARREO Science Team Report. Available at http://clarreo.larc.nasa.gov.

Discuss the Article

Inter-comparison of CrIS full resolution radiances with IASI

by Likun Wang, Yong Han, Yong Chen, Xin Jin, Xiaozhen Xiaong, and Denis Tremblay, NOAA

The radiometric and spectral consistency among the Atmospheric Infrared Sounder (AIRS), the Infrared Atmospheric Sounding Interferometer (IASI), and the Cross-track Infrared Sounder (CrIS) is fundamental for the creation of long-term infrared (IR) hyperspectral radiance benchmark datasets for both inter-calibration and climate-related studies. These measurements are used not only to retrieve atmospheric temperature and humidity profiles, but more importantly, to be directly assimilated into numerical weather prediction (NWP) models as inputs. Moreover, owing to their hyperspectral nature and accurate radiometric and spectral calibration, hyperspectral IR radiances have been used as a reference to independently assess the spectral and radiometric calibration accuracy of broad- and narrow-band IR instruments, as well as for long-term climate change monitoring, strict testing of climate model outputs, and validation of numerical weather model analyses and re-analyses.

CrIS is a step-scan Fourier transform spectrometer onboard the Suomi NPP spacecraft. It can be operated in two modes: normal and full spectral resolution (FSR) mode (shown in Fig.1). The CrIS radiance spectrum (without apodization) covers three IR bands from 650 to 1095 cm^{-1}, 1210 to 1750 cm^{-1}, and 2155 to 2550 cm^{-1} with spectral resolutions of 0.625 cm^{-1}, 1.25 cm^{-1}, and 2.5 cm^{-1} at the normal operational mode (a total of 1305 spectral channels); it has an identical spectral resolution of 0.625 cm^{-1} in all three bands at the FSR mode (a total of 2211 channels).

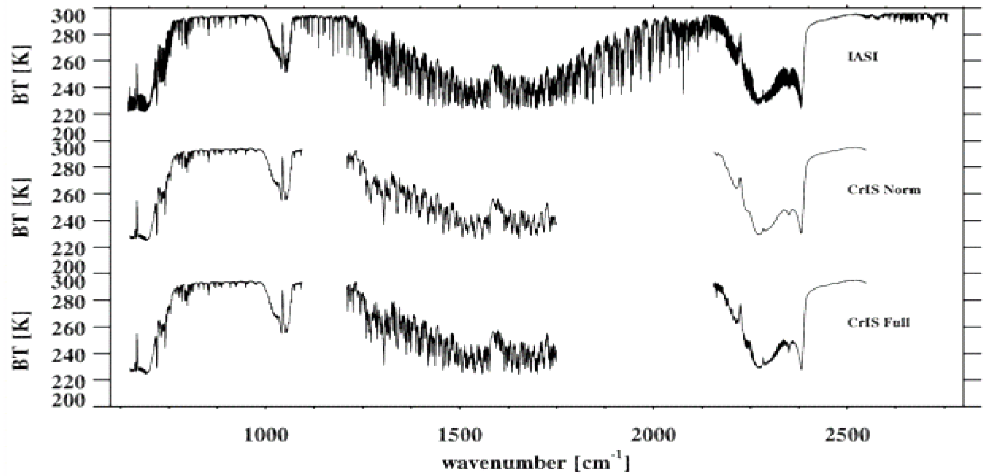

Figure 1. IASI and CrIS normal-resolution and full-spectral-resolution spectra simulated by LBLRTM using an identical tropical atmospheric profile over ocean.

CrIS has been operated at the normal mode since launch (except for several tests on 23 February 2012, 12 March 2013, and 27 August 2013). CrIS has been switched into the FSR mode since 4 December 2014. On one hand, the official CrIS sensor data records (SDR) are still processed and released as the normal resolution by Interface Data Processing Segment (IDPS). On the other hand, the NOAA/STAR CrIS SDR team off-line processed and released CrIS FSR SDR products (Han et al. 2015), which can be obtained at ftp://ftp2.star.nesdis.noaa.gov/smcd/xxiong/.

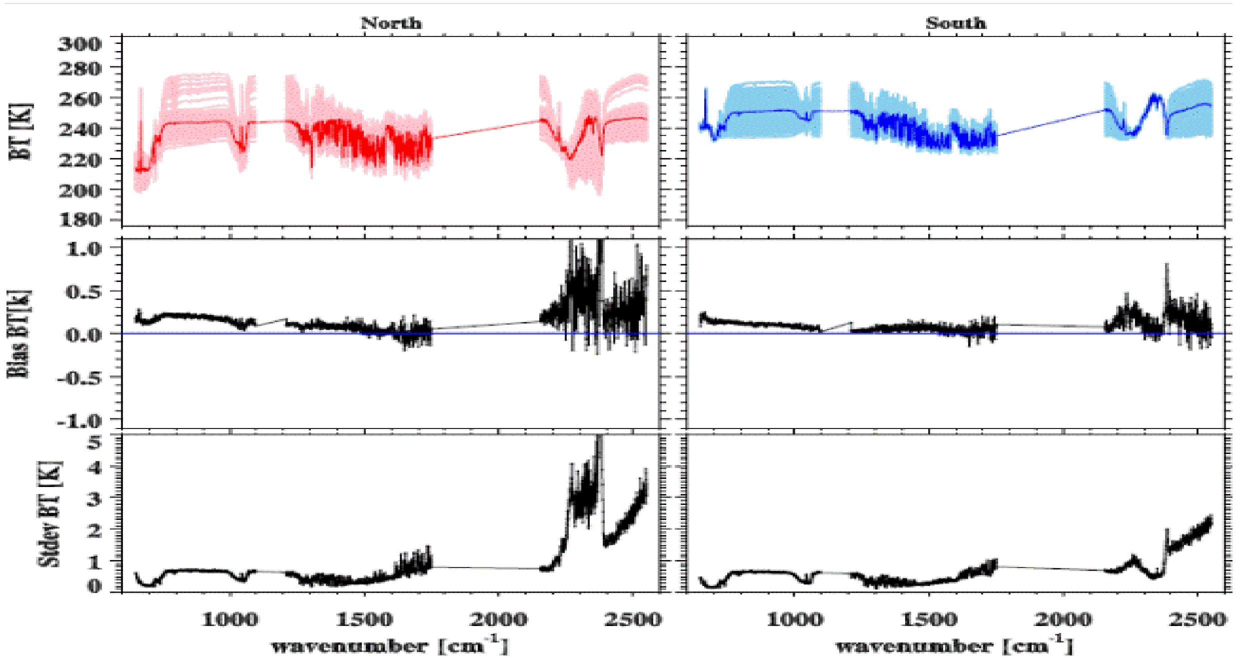

Figure 2. CrIS spectral distribution (top) for CrIS-IASI on MetOp-B for North Polar SNOs (left) and South Polar SNOs (right) and the mean (middle) and standard deviation (bottom) of CrIS-IASI BT differences. The solid lines in the top figure represent the average spectrum from all the samples.

Inter-comparison of the normal resolution CrIS SDR with AIRS and IASI have been reported by several studies from Wang et al. 2014, Jouglet et al. 2014, Tobin et al, 2013, and Strow et al 2013. All studies suggest that the CrIS normal resolution SDR agree well with these instruments. This study reports preliminary results of inter-comparison of FSR CrIS SDR with IASI spectra. During 26-28 December 2014, CrIS met IASI on MetOp-B almost every orbit for three days, the so-called simultaneous nadir overpass (SNO) events. The spectra

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from two sensors are paired together through strict spatial and temporal collocation. The uniform scenes are selected by examining the collocated Visible Infrared Imaging Radiometer Suite (VIIRS) pixels. Their brightness temperature (BT) differences are then calculated by converting the IASI spectra onto CrIS spectral grids. Specifically, five steps are performed, including: 1) converting IASI spectra to interferograms using Fourier transform; 2) de-apodizing IASI interferograms using IASI apodization functions; 3) truncating the IASI interferograms based on CrIS OPD specification; 4) apodizing truncated interferograms using CrIS Hanning apodization functions; and 5) transforming interferograms back into spectra using inverse Fourier transform. The simulation study indicates that this method is very accurate and re-sampling errors (from IASI to CrIS) are less than 0.02K for all three bands (Wang et al. 2014).

A total of 144 pairs of spectra collocated in the North Polar Region and 187 spectra in South Polar Region are identified. Figure 2 shows the CrIS spectral distribution as well as the mean and standard deviation of CrIS-IASI BT differences. The preliminary results indicate that CrIS full spectral resolution SDR products agree well with IASI in the longwave and middle-wave bands, where CrIS is slightly warmer than IASI by approximately 0.1-0.2 K, which is similar to the inter-comparison results between CrIS normal resolution SDR with IASI on MetOp-A and MetOp-B. Finally, a ringing pattern can be seen in the shortwave band, which is probably due to the large noise found for cold scenes for both sensors. The root cause of this bias pattern is still under investigation. Inter-comparison of both FRS and normal resolution CrIS SDR will be continued to monitor the calibration stability of CrIS sensor by the NOAA/NESDIS/STAR CrIS SDR team.

References:

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Discuss the Article

The status of long-term data processing in NSMC

by Jian Liu, Peng Cui, Zhaojun Zheng and Na Xu, NSMC/CMA

Since the 1970's, the National Satellite Meteorological Center (NSMC) has received, processed and archived large amounts of various satellite data. The archived data amount is more than 6.1Pb. All these archived data include FengYun(FY)-2, FY-1, FY-3, NOAA, GMS series and other satellite data.

The data are reprocessed since 1998. This reprocessed satellite data include NOAA/AVHRR, FY-2C/2D/2E, FY-1C/1D and GMS/MTSAT data. The processing flow includes reposition, recalibration, product retrieval and retrieval quality evaluation.

Recalibration is the foundation for long-term data reprocessing. For the FY-series satellite data, the recalibration coefficients come from GSICS. Operational calibration of FY-2D/E has used the GSICS inter-calibration coefficients since the beginning of 2012. The calibration biases were greatly reduced to about 0.5 at 290K and1K at 250K and have been stable except during eclipse periods(Hu et al, 2010,Zhang and Gunshor, 2013,Hu et al, 2013). This large improvement can be seen in Figure. 1. After one year, the new CIBLE (Calibration of Inner Blackbody corrected by Lunar Emission) was applied to the operation of FY-2D/E, and GSICS was back to monitoring the calibration accuracy based on the GSICS reference instrument AIRS and IASI. It is shown that the new calibration is more stable than the old operational calibration, but there is still calibration bias. For the other satellites, such as the NOAA series satellite data, the calibration coefficients come from external sources webpage, such as ISCCP web page.

Under the inter-calibration of imager observations from time-series of geostationary satellites (IOGEO) project, a Fundamental Climate Data Record (FCDR) of calibrated and quality-controlled FY-2 imager data is

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planned to be generated, containing the visible, IR window and water vapor absorption channels. The observations of FY-2C/D/E will be recalibrated for the infrared window and water vapor channels. The time series cover seven years from 2005 to 2012. According to working paper of CMA in CGMS-42 (CMA- WP-05) meeting, the relative accuracy of the new calibration results is expected to be better than 1K for scene temperatures of 290K. A new recalibration approach will be developed for IR FCDRs generation, considering nonlinear correction and diurnal variation. According to calibration reprocessing schedule, at the end of 2015, recalibration for FY-2C/2D/2E during 2005-2012 will be finished. Then recalibration for FY-2D/2E/2F/2G during 2013-2018 will be finished by 2019.

Based on recalibration, cloud amount, land surface temperature, snow coverage, vegetation index and outgoing long wave radiation have

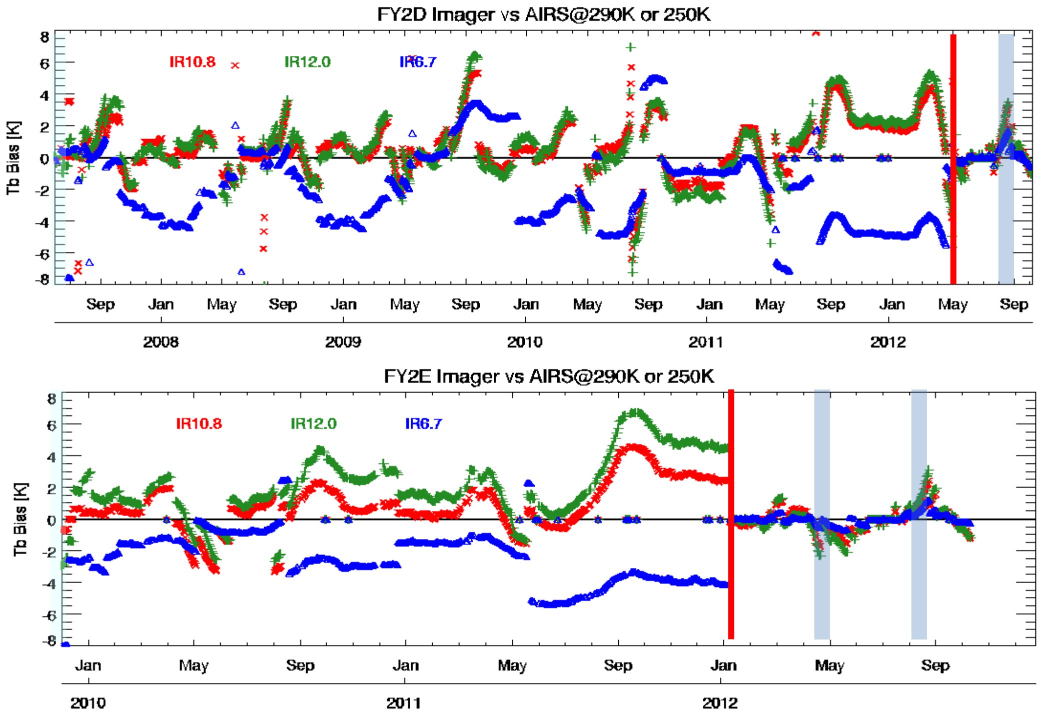

Figure 1. The time series of brightness temperature bias at high temperature end of FY-2D/FY-2E since it was launched (window channel @290K bias, water vapor channel @ 250K bias)(CGMS-42 CMA-WP-06)

been selected to build a long-term data set from 1988 to 2008. Synoptic and similar satellite data (such as EOS/Terra and EOS/Aqua) have been used to evaluate the accuracy of the processed data. Evaluation results show that the bias between two kinds of data comes from many factors, such as retrieval algorithm and different data. Except for the algorithm effect, the closer the different satellite observation data are, the smaller the bias between different data. This shows that inter-calibration between different satellite data plays an important role in evaluating data quality. The first version of the long-term data set is complete. The second version of long term data will be processed according to GSICS' schedule.

References:

Zhang, Y. and M. M. Gunshor, 2013: Intercalibration of FY-2C/D/E infrared channels using AIRS. *IEEE Trans. Geosci. Remote Sens.*, **51(3-1)**, 1231-1244.

Hu, X., N. Xu, F. Weng, Y. Zhang, L. Chen, and P. Zhang, 2013: Long term monitoring and correction of FY-2 infrared channel calibration using AIRS and IASI. *IEEE Trans. Geosci. Remote Sens.*, **11 (10)**, 5008-5018.

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Project for Inter-calibration of Long-term Data Set of FY-2 Imager Observations (IOGEO). *CGMS-42 CMA-WP-06*, Guangzhou, China.

Hu X. Q., P, Zhang, and Y. Zhang, 2010: Inter calibration results analysis for FY-2C/2D based on AIRS and IASI. *GSICS Quarterly* **4(1)**.

Discuss the Article

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News in this Quarter

Outcomes of the Joint GSICS-CEOS/IVOS Lunar Calibration Workshop

by Sébastien Wagner (EUMETSAT), Thomas Stone (USGS), Sophie Lachérade (CNES), Bertrand Fougnie (CNES), Xiaoxiong Xiong (NASA), Tim Hewison (EUMETSAT)

In December 2014 experts from 14 agencies and departments attended the joint GSICS – CEOS/IVOS Lunar Calibration Workshop organized by EUMETSAT in collaboration with USGS, CNES and NASA (Figure 1). This represents potentially more than 25 instruments capable of observing the Moon. These instruments (listed in Table 1) cover a spectral range from about 0.4µm to 2.3µm.

The main objectives of the workshop were

i) to work across agencies with the GSICS Implementation of the ROLO model (GIRO) - a common and validated implementation of the USGS lunar radiometric reference,
ii) to share knowledge and expertise on lunar calibration and
iii) to generate for the first time a reference dataset that could be used for validation and cross-comparisons. This dataset is meant to be a sample of typical lunar acquisitions from each registered instrument. The workshop addressed various aspects of the data preparation that are critical to lunar calibration, in particular estimating accurately the oversampling factor.

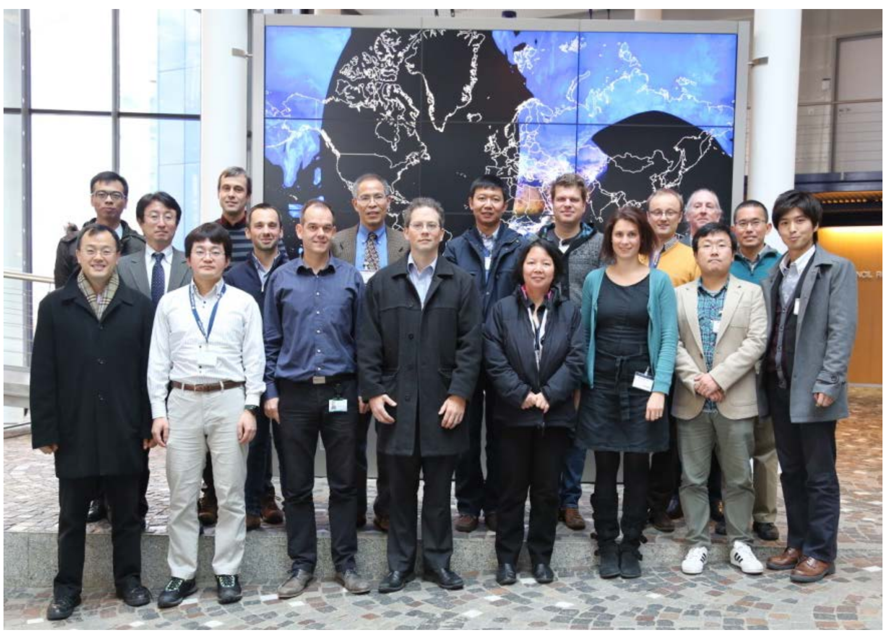

Figure 1: Fourteen agencies were represented (including remote participations) at the Lunar Calibration Workshop organized in Darmstadt (1-4 December 2014).

This factor, whose value is specific to each instrument, can be constant or vary in time and space. Additionally, the difficulty of estimating deep space count offsets and removing potential artifacts from the images (such as stray light) were also discussed. The large variety of scanning mechanisms and acquisition configurations, as illustrated by Figure. 2, adds to the difficulty of identifying potential deficiencies in the image processing and the lunar data preparation.

A set of actions and recommendations [1] was agreed with the participants to review the various aspects of their image processing with a special focus on the estimation of the oversampling factors.

Most of the group had prepared data for the instruments they presented at the workshop and processed them with the GIRO application as provided by EUMETSAT. These data were collected to establish the first version of a reference lunar calibration dataset.

The participants to the lunar calibration workshop endorsed the GIRO to be the established publicly-available reference for lunar calibration, directly traceable to the USGS ROLO model.

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Table 1. Instruments with lunar observation capabilities, with the minimum number of Moon observation expected to be provided to the Lunar Calibration Dataset (more observations may be available).

Team	*Satellite*	*Sensor*	*G/L*	*Dates*	*Number of obs (GSICSdataset)*	*Phase angle range (°)*
CMA	**FY-3C**	**MERSI**	**LEO**	**2013-2014**	**9**	**[43 ,57]**
CMA	**FY-2D**	**VISSR**	**GEO**	**2007-2014**		
CMA	**FY-2E**	**VISSR**	**GEO**	**2010-2014**		
CMA	**FY-2F**	**VISSR**	**GEO**	**2012-2014**		
JMA	**MTSAT-2**	**IMAGER**	**GEO**	**2010-2013**	**62**	**[-138,147]**
JMA	**GMS5**	**VISSR**	**GEO**	**1995-2003**	**50**	**[-94,96]**
JMA	**Himawari-8**	**AHI**	**GEO**	**2014-**	**-**	
EUMETSAT	**MSG1**	**SEVIRI**	**GEO**	**2003-2014**	**380/43**	**[-150,152]**
EUMETSAT	**MSG2**	**SEVIRI**	**GEO**	**2006-2014**	**312/54**	**[-147,150]**
EUMETSAT	**MSG3**	**SEVIRI**	**GEO**	**2013-2014**	**45/7**	**[-144,143]**
EUMETSAT	**MET7**	**MVIRI**	**GEO**	**1998-2014**	**128**	**[-147,144]**
CNES	**Pleiades-1A**	**PHR**	**LEO**	**2012**	**10**	**[+/-40]**
CNES	**Pleiades-1B**	**PHR**	**LEO**	**2013-2014**	**10**	**[+/-40]**
NASA-MODIS	**Terra**	**MODIS**	**LEO**	**2000-2014**	**136**	**[54,56]**
NASA-MODIS	**Aqua**	**MODIS**	**LEO**	**2002-2014**	**117**	**[-54,-56]**
NASA-VIIRS	**NPP**	**VIIRS**	**LEO**	**2012-2014**	**20**	**[50,52]**
NASA-OBPG	**SeaStar**	**SeaWiFS**	**LEO**	**1997-2010**	**204**	**(<(10 , [27-66])**
NASA/USGS	**Landsat-8**	**OLI**	**LEO**	**2013-2014**	**3**	**[-7]**
NASA	**OCO-2**	**OCO**	**LEO**	**2014**		
NOAA-STAR	**NPP**	**VIIRS**	**LEO**	**2011-2014**	**19**	**[-52,-50]**
NOAA	**GOES-10**	**IMAGER**	**GEO**	**1998-2006**	**33**	**[-66, 81]**
NOAA	**GOES-11**	**IMAGER**	**GEO**	**2006-2007**	**10**	**[-62, 57]**
NOAA	**GOES-12**	**IMAGER**	**GEO**	**2003-2010**	**49**	**[-83, 66]**
NOAA	**GOES-13**	**IMAGER**	**GEO**	**2006**	**11**	
NOAA	**GOES-15**	**IMAGER**	**GEO**	**2012-2013**	**28**	**[-52, 69]**
VITO	**Proba-V**	**VGT-P**	**LEO**	**2013-2014**	**25**	**[-7]**
KMA	**COMS**	**MI**	**GEO**	**2010-2014**	**60**	
AIST	**Terra**	**ASTER**	**LEO**	**1999-2014**	**1**	**-27.7**
ISRO	**OceanSat2**	**OCM-2**	**LEO**	**2009-2014**	**2**	
ISRO	**INSAT-3D**	**IMAGER**	**GEO**	**2013-2014**	**2**	

A process to formalize this traceability was discussed and will be implemented in the coming months. The important aspects of error budget and uncertainty assessment were also addressed during a full-day practical session using the existing lunar calibration dataset. This assessment needs to be continued by each data provider but participants agreed to prepare instrument cross-comparisons and inter-calibration products as defined by GSICS.

It was also agreed by all participants that a policy for the usage of the lunar calibration data and the GIRO should be officially established. For the time being, all participants agreed that access to the dataset is restricted to the Lunar Calibration Workshop participants (including groups working on future missions).

Once the data and GIRO usage policy is formalized, a suitable access procedure will be defined on the GSICS Wiki webpage [3] . Requests from new participants will be first forwarded to the Lunar Calibration Workshop community for prior agreement. Regarding the GIRO, access to the application and the source code will be provided following a similar procedure.

A mechanism to ensure traceability will be defined in order to ensure the validity of cross-comparisons and inter-calibration between instruments. The current Moon observation dataset is expected to grow with the availability of additional observations from past, current and future missions.

Once the data and GIRO usage policy is formalized, a suitable access procedure will be defined on the GSICS Wiki webpage [3]. Requests from new participants will be first forwarded to the Lunar Calibration Workshop community for prior agreement. Regarding the GIRO, access to the application and the source code will be provided following a similar procedure. A mechanism to ensure traceability will be defined in order to ensure the validity of cross-comparisons and inter-calibration between instruments. The current Moon observation dataset is expected to grow with the availability of additional observations from past, current and future missions. All participants agreed on EUMETSAT pursuing its efforts in developing and maintaining the GIRO in collaboration with USGS to ensure traceability to the reference ROLO model [2].

Looking at the future, further effort is required to achieve inter-calibration between instruments. First, oversampling factor determination is currently a major source of uncertainty in the evaluation of the observed lunar irradiance.

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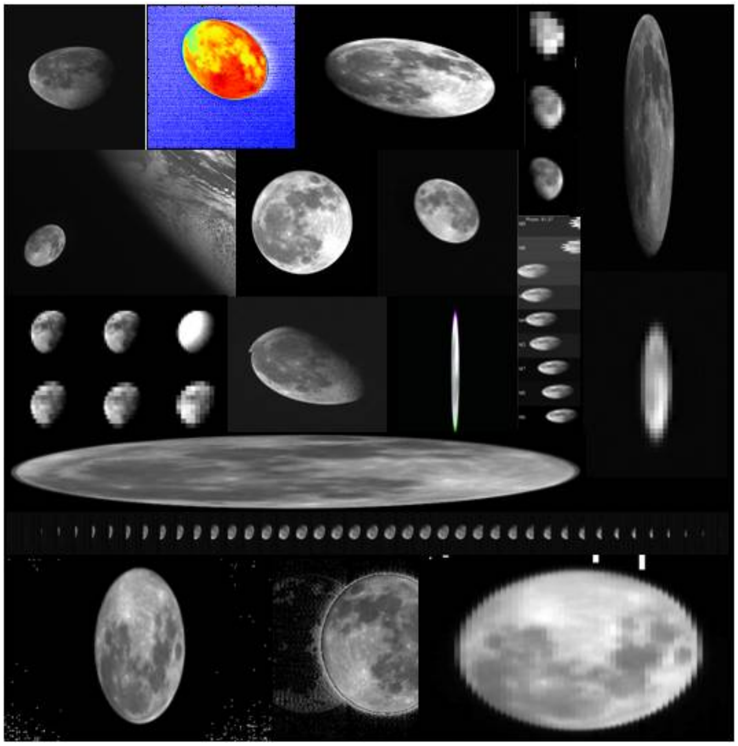

Figure 2. Examples of Moon observations from the participating instruments, illustrating the variety of acquisition mechanisms.

Second, instruments should be drift-corrected in order to use the irradiance as the quantity for comparison or inter-calibration. Third, *Spectral Band Adjustment Factors* must be derived from GIRO and validated. Finally, the lunar calibration reference needs to be tied to an absolute scale that is SI traceable. In order to achieve this, further measurement campaigns are needed, requiring a longer and larger project and financial framework.

The Lunar Calibration Workshop successfully brought together the GSICS and CEOS/IVOS communities. It involved not only teams with existing lunar data but also scientists and engineers preparing for future missions. The level of participation and discussion show the increasing interest to use lunar calibration for instrument performance monitoring, cross-comparisons and inter-calibration. A list of decisions, actions and recommendations [1] was established to pursue this international collaboration. The most obvious sign of interest in continuing this activity was that all participants agreed on the need to organize at a suitable date another Lunar Calibration Workshop.

References:

[1] GSICS/CEOS-IVOS Lunar Calibration Workshop Summary, https://gsics.nesdis.noaa.gov/pub/Development/LunarCalibrationWorkshop/SummaryoftheLunarCalibrationWorkshop.pdf
[2] Kieffer, H., H., Stone, T. C., 2005, *The Spectral Irradiance of the Moon*, The Astronomical Journal, **129**, pp.2887-2901
[3] GSICS Lunar Calibration wiki page, https://gsics.nesdis.noaa.gov/wiki/Development/LunarWorkArea

DSCOVR and SMAP Launched

by Manik Bali, NOAA

The beginning of 2015 saw the launch of two key satellite missions for Earth and Space observations. These are the Soil Moisture Active Passive observatory (SMAP) which was launched on 31 January 2015, and the Deep Space Climate Observatory (DSCOVR) that lifted off from Cape Canaveral, FL on 11 February 2015.
DSCOVR is a deep space mission that will take six months to cover a distance of 1.6 million km to reach its final orbit place at the Lagrangian point (L1; Figure. 1). The primary instruments onboard DSCOVR are:

1. Solar Wind Plasma Sensor and Magnetometer (PlasMag) that will measure solar wind.
2. National Institute of Standards and Technology Advanced Radiometer (NISTAR) that will take measurements of radiation from Earth in UV and NIR bands
3. Earth Polychromatic Imaging Camera (EPIC), sensitive to 317–779 nm;
4. Electron Spectrometer (ES), Pulse Height Analyzer (PHA).

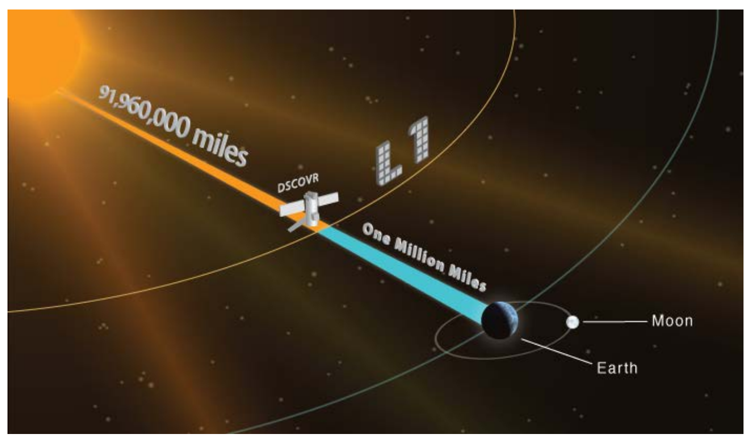

Figure 1. The final resting place of DSCOVR. Image courtesy NOAA.

As pointed out by Jérôme Lafeuille, Chief, Space-based Observing Systems (WMO): “The combination of the broadband NISTAR and the narrow-band EPIC instrument will provide a good sampling of the upward shortwave radiation spectrum.

Further located at L1, DSCOVR will provide a continuous measurement of the Sunlit part of the Earth, which is unique”.

Highlighting the relevance of EPIC to GSICS, Lawrence. E. Flynn, GSICS UV subgroup Vice Chair, emphasizes that due to its unique position at the L1 point, it would always observe the sunlit side of the Earth and hence can be used as a transfer measurement for double difference comparisons based on daily GEO and orbital LEO under flights. Lawrence who had earlier introduced EPIC's capabilities in the Asia Oceania Meteorological Users Conference (AOMSUC) in China through a poster, further states that EPIC will use solar and lunar observations and on-board LEDs as well as vicarious target trending to independently characterize its calibration stability.

Meanwhile, SMAP has an active as well as passive microwave sensor and aims at measuring surface soil moisture and freeze/thaw state. The idea is to integrate an L-band radar and an L-band radiometer as a single observation system combining the relative strengths of active and passive remote sensing for enhancing soil moisture measurement. The optimized instrument design includes a 6-m diameter, conically scanning, deployable mesh reflector antenna. It is envisaged that SMAP would provide accurate measurements of soil moisture that would help in forecasting and climate studies.

References:
http://smap.jpl.nasa.gov/science/objectives/
http://www.nesdis.noaa.gov/DSCOVR/

Announcements

GSICS Users Workshop to be held 21-25 September, 2015 in Toulouse, France

by Tim Hewison, EUMETSAT

The 2015 GSICS Users Workshop (GUW) will be held with the EUMETSAT Meteorological Satellite Conference. This conference will be held from 21 to 25 September in Toulouse, France and will be collocated in space and time (not exactly!) with the SPIE European Remote Sensing Conference. The GUW will take place on the afternoon of Tuesday 22 September, during a poster session of the conference. Users and potential users of GSICS products, who are interested in attending are invited to contact Tim.Hewison(at)eumetsat.int.

The Annual GRWG+GDWG Meeting to be held 16-21 March 2015 in New Delhi, India

by Manik Bali, NOAA

The annual GSICS (GRWG+GDWG) meeting will be held in New Delhi, India 16-21 March, 2015. The meeting is hosted by the India Meteorological Department (IMD) and the venue will be Prithvi Bhavan, India Meteorological Department, Ministry of Earth Sciences (MoES) Lodi Road, New Delhi-110003, India.

Details of the meeting are being worked out (Visit: GSICS Wiki). The meeting will begin with a Mini Conference on 16 March 2015. This will be followed by a Plenary on 17 March 2015. The plenary will cover topics related to the IR-MW-UV subgroups and also GPRC reports from members. Members will also get the opportunity for a guided tour of IMD. Following this, the GSICS Data Working Group (GDWG) and the GSICS Research Working Group (GRWG) will break out into parallel sessions while converging on important topics. The meeting will finish with a wrap up session where summary of meeting and status of action items will be discussed.

GSICS-Related Publications

Hailong, P. et al., 2014: HY-2A satellite calibration and validation approach and results, *IGARS*S pp. 4528-4531

Liu, Y. et al.,2014: A preliminary crossover calibration result for HY-2. *2014 IGARSS SYMPOSIUM* pp. 688-691.

Lu, F. et al.,2014: Evaluation of nonlinear calibration on the satellite TIR image applications. *SPIE PROCEEDINGS* Vol. 9264 926413.

Maidment, R. et al., 2014: The 30 year TAMSAT African Rainfall Climatology And Time series (TARCAT) data set *J. Geophys. Res.-Atmos.*, **119 (18)**, 10619-10644.

Mishra, N. et al.,2014: Radiometric Cross Calibration of Landsat 8 Operational Land Imager (OLI) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) *Remote Sens.* **6**, 12619-12638.

Quan, W., 2014: Vicarious cross-calibration of the China Environment Satellite using nearly simultaneously observations of Landsat-7 ETM+ Sensor. *Journal of Indian Society of Remote Sensing*, **42 (3)**, 539-548.

Wu, H. et al., 2014: Inter-calibration of VIRR/FY-3B infrared channels with AIRS/Aqua channels 2014 *IGARSS* pp. 1999-2002.

Yu, F., Wu, X., Grotenhuis, M and Qian, H., 2014: Inter-calibration of GOES Imager visible channels over the Sonoran Desert. *J. Geophys. Res.-Atmos*., **119**, 8639–8658, doi:10.1002/2013JD020702.

Zhang, Y. et al., 2014: Onboard blackbody calibration models of FY-2D SVISSR based on GSICS. *SPIE PROCEEDINGS* Vol. 9264 92640S.

Zou, X., Weng, F and Yang, H.,2014: Connecting the time series of microwave sounding observations from AMSU to ATMS for long-term monitoring of climate. *J. Atmos. Oceanic Technol.*, **31**, 2206–2222. doi: http://dx.doi.org/10.1175/JTECH-D-13-00232.1

Submitting Articles to GSICS Quarterly Newsletter:

The GSICS Quarterly Press Crew is looking for short articles (~800 to 900 words with one or two key, simple illustrations), especially related to cal/val capabilities and how they have been used to positively impact weather and climate products. Unsolicited articles are received for consideration anytime, and if accepted, will be published in the next available newsletter issue after approval/editing. Note the upcoming spring issue will be a general issue. Please send articles to manik.bali@noaa.gov.

With Help from our friends:

The GSICS Quarterly Editor would like to thank Changyong Cao for the lead article in this issue. Thanks are also due to Jerome Lafeuille , Xiangqian Wu, Fangfang Yu, Tim Hewison and Lawrence E. Flynn for reviewing the articles in this issue.

GSICS Newsletter Editorial Board